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Title:

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MICROSTRUCTURAL EFFECTS IN PBX 9501 DAMAGED BY SHEAR IMPACT

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Various microstructural mechanisms have been suggested for ignition in explosives subjected to impact by low-velocity projectiles. In this study, the effects of shear on the microstructure of PBX 9501 are described. The pseudo two-dimensional, shear-impact experiment, previously employed by Asay, et al. to dynamically study strain localization, is engaged to create shear damage. Impact is achieved by utilizing a gas gun projectile to drive a plunger, which is in contact with the explosive. Post-test microstructural analysis corroborates the observations of other researchers using different diagnostics. Observed features include evidence of shear displacement, the formation of a wedge structure, and reaction in open cracks emanating from the high shear region of the sample. This study also contributes insights concerning the behavior of HMX particles subjected to shear stress.

INTRODUCTION

Shear phenomena in PBX 9501 (95% HMX and 5% polymeric binder, by weight) have been investigated by many researchers using various modeling approaches and experimental techniques. Heating from shear strain, through sliding friction or viscous effects, is considered a likely hot spot mechanism that could lead to ignition (1). This work examines the effects of shear impact on the microstructure of PBX 9501. Polarized light microscopy is applied to post-test materials which have been subjected to varying degrees of insult.

Earlier microscopical work (using electrons and light) at Los Alamos characterized PBX 9501 in nominal states as molding powder and pressed pieces (2), (3), and in damaged states by post-test analysis of material from modified Steven tests and self-sustained combustion in ambient pressure air (4). That body of work provides a foundation from which to examine the effects of shear impact. Results from experiments conducted near the reaction threshold are used to postulate a damage sequence that leads to ignition.

EXPERIMENTS

Shear impact experiments were conducted using a light gas gun to launch a projectile, which impacts a plunger resting in contact with the explosive sample (rectangular slab of PBX 9501 25 mm by 20 mm by 2 mm). The explosive is confined on all sides except for a small void volume in each corner. The assembly is a sandwich of top plate, explosive-plunger subassembly, and bottom plate. This facilitates removal of the damaged explosive. A schematic of the plan view (post-test) with top confinement removed is provided in Fig. 1. This test arrangement has been used by Asay, et al. with various plunger shapes to observe strain localization using speckle photography (5).

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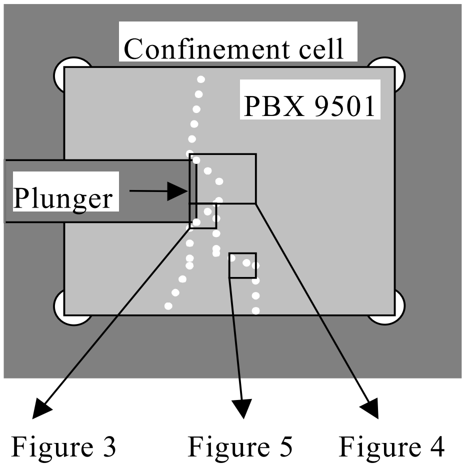

Figure 1. Schematic representation of experiment assembly and crack patterns in PBX 9501 (post-test).

The plunger velocity is estimated to be on the order of 100 m/s, which is near the threshold for reaction in this configuration. Samples without obvious reaction (no open cracks) are removed, intact, as one piece. Other samples exhibit definite open cracks and can only be removed as multiple pieces. The relative orientations are preserved through the subsequent steps, enabling the creation of a montage view of the entire sample.

The damaged sample is prepared for examination by exposing to modest vacuum, introducing low viscosity epoxy, slow curing under 3.45 MPa (500 psig) gas pressure, and polishing in traditional fashion. Observations are made by surveying multiple samples at various magnifications with a Leica DM RXA light microscope. Digital images are captured using a Spot camera (Diagnostics Instruments). Montages of large-field images are created manually to provide an overview of damage patterns.

RESULTS AND DISCUSSION

Isolated instances of obvious shear displacement in individual crystals were observed in some samples that showed no evidence of reaction. Figure 2 is an image from an experiment using lower density PBX 9501 (1.825 g/cm^3) and a 19 mm radius plunger. While there is definite slip in an individual crystal, there are no indications of melt or decomposition. Further, the displacement cannot be traced as a pattern in the surrounding material. More highly resolved images show some measure of comminution in the closed cracks. Such generation of fine powder HMX may be important in ignition scenarios involving sliding friction.

Figure 1 provides a representation of the blunt plunger experiment and observed, post-test, crack patterns (white dots). A wedge structure just ahead of the plunger is consistently observed for samples with or without open reaction cracks. Henson, et al. (6), utilizing a Hadland Imacon 468 camera in a very similar experiment, observed self-illumination from the leading edges of a “compression cone” 210 microseconds after impact. Peterson, et al. (7), observed a triangular-shaped dead zone just ahead of the punch in a low-velocity, intrusion experiment on sugar mock PBX 9501. The leading edges of the triangle formed an effective wedge displacing the material ahead of it and protecting the material in the dead zone.

Figure 3 is a micrograph from an experiment which resulted in no open cracks and was, therefore, deemed below reaction threshold. The position of the micrograph relative to the plunger is shown in Fig. 1. One edge of the wedge structure can be seen running from the lower left to upper right. The evenly shaded region to the left is where

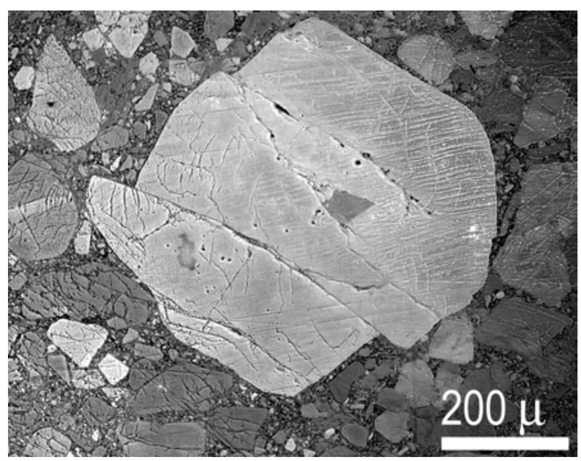

Figure 2. Shear displacement in single crystal of HMX.

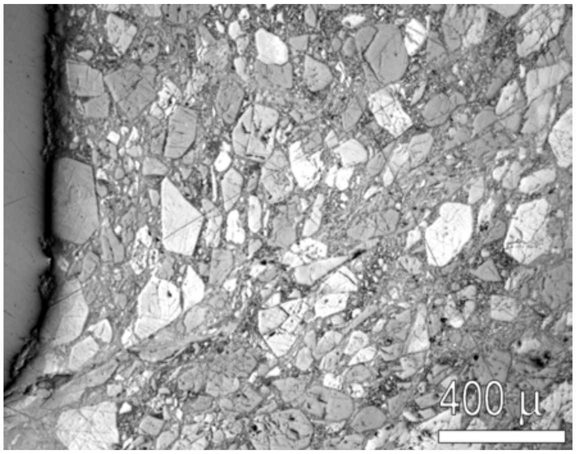

Figure 3. Discontinuity showing wedge structure.

the plunger came to rest (filled with mounting epoxy in the image). While the discontinuity is discernible, no correlation can be made between particles on either side that would indicate the magnitude of relative shear displacement. Possibly, the plunger pushed the wedge structure well beyond the original field of particles.

The width of this shear zone is difficult to assess. While the principal discontinuity is very sharp, there appears to be a secondary discontinuity about a half-particle-width below it. The extent of comminution is also difficult to assess. Unlike shear bands in some metal alloys, there is a pronounced absence of particles with large plastic strains in the shear zone.

Figure 4 encompasses most of the wedge structure from an experiment with obvious indications of reaction. The sample area represented is shown in Fig. 1. As with Fig. 3, the plunger face came to rest against the left edge shown in the micrograph. The microstructure inside the wedge structure is fairly typical of a pressed piece suggesting that it may have translated without much additional damage. The leading edges of the wedge were mostly separated from the surrounding material by open cracks. The top edge shows some connectivity which resembles the discontinuity illustrated by Figure 3. The open cracks from this experiment are different in character than cracks we have observed which were created by mechanical means. For example, these cracks have smooth edges across multiple particle boundaries suggesting melting or some level of reaction from the explosive. Comparing Fig. 3 with Fig. 4 infers that formation of the wedge precedes reaction of the explosive.

Microstructural analysis of the entire sample from the same experiment as shown in Fig. 4 reveals a number of open cracks emanating from the wedge region which appear to have burned surfaces. Figure 5 in an example of such a tributary crack. Its relative location in the sample is shown in Fig 1. The narrowest portion of the crack is downstream of the wedge. Here we observe undulating, smooth edges across multiple particle boundaries, again suggesting thermal damage as the last stage of insult. However, the three single particles of HMX in the center show very little evidence of shear displacement. It is clear (by contrasting gray levels) that these three particles have remnants on both sides of the crack. They are shifted in a shear direction very little, if at all, relative to each other in the plane of the image. We postulate that separation occurred by tension cracking which was followed by flame in the crack. Although generally confined, we expect that there is enough free volume in the assembly to allow tension cracking.

The results of cookoff ignition experiments conducted by Dickson, et al. (8) suggest the following sequence for confined PBX 9501 initially at elevated temperature. Thermal ignition leads to rapid, local pressurization. This introduces tensile stresses which create highly luminous cracks (more for weaker confinement). "The freshly opened surfaces appear to be ignited as the cracks progress."

Post-test analysis cannot distinguish these cookoff cracks from impact cracks. If we assume that shear strain has stimulated thermal ignition near the wedge, Figure 5 certainly appears to be post-test evidence of reaction in a crack whether the crack was created by impact stress or cookoff pressurization.

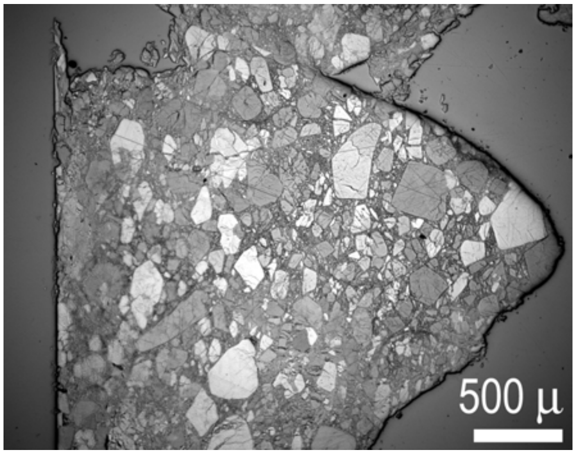

Figure 4. Evidence of reaction at boundary of wedge structure.

It should be noted that there is no evidence of increased particle comminution, or plastic deformation near the open cracks. While this can be used to support the notion of tension cracking, it could also be argued that if either condition were present earlier in the damage process the evidence would have been consumed by hot, product gases. This would certainly be the case if fine HMX powder had been present.

CONCLUSIONS

Shear strains were introduced into PBX 9501 samples using an impact-plunger technique. Detailed, post-test analysis is reported for samples damaged near the reaction threshold. The evolution of damage is postulated as follows. Intrusion of a blunt plunger creates a wedge structure. High shear strains or strain rates along the leading wedge edges stimulate thermal ignition. Tension crack networks are generated in the bulk sample either as a result of impact stresses or by pressurized product gases. Flames or hot gases from the original ignition sites flow in the cracks stimulating additional reaction of the explosive on the crack surfaces.

Further work is needed to probe the mechanism by which thermal ignition is stimulated. The question is not resolved whether sliding friction (inter- or intra- crystalline) is responsible or viscous heating from shear localization, or some combination.

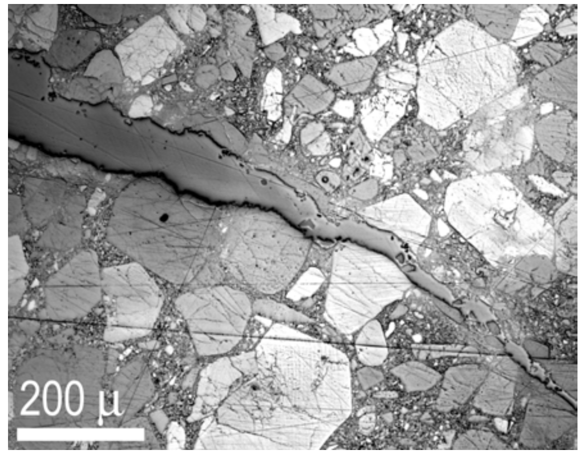

Figure 5. Evidence of reaction in tributary crack without apparent shear displacement.

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